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EVALUATION IN THE U.S.**

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# **A REVIEW OF NUCLEAR REACTION DATA EVALUATION IN THE U.S.**

**by**

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In the most general sense, nuclear data evaluation has been a developing activity for the past forty years. The first report I am aware of that included evaluated nuclear data was written in 1944 by Dr. Katherine Way under the auspices of the Manhattan District Project. It contained a few values of fission cross sections in the MeV region for isotopes of importance at that time.

In the decade that followed, several compilations of measured neutron interaction data were issued; some with, and some without, "eye-guide" curves. Notable among these were AECU-2040 which was the first "Wallpaper Book", and Adair's graphs of "Neutron Cross Sections of the Elements", that were published in Reviews of Modern Physics 22, 249, (1950).

By 1957 several reports were issued that presented what would now be regarded as first approximations to evaluated data sets for a few materials. Probably the best examples are the reports issued by the Nuclear Development Corporation of America that presented "best values" for all energetically

possible reactions for a few of the lighter elements, e.g., carbon and oxygen. For the first Geneva Conference in 1955, numerous review papers were issued and notable among these was BNL 325 which was an update of AECU 2040. It presented graphs of measured cross sections without errors plus eye-guide curves. For reactions and energy regimes where measurements had not been made, no effort was made to estimate the values that might be expected had measurements been done. It also presented, especially in its supplement and later editions, recommended values for thermal and resonance parameter data. In 1956 the first of edition of BNL 400 presented values for angular distributions of secondary neutrons. This was the first widely distributed compilation of such data.

In 1958, I wrote UCRL 5351, "Semi-Empirical Cross Sections, .001-15 MeV". It contained graphs of cross sections and a discussion of how I arrived at the values, for all energetically possible reactions that I estimated would have cross sections greater than a few millibarns somewhere in the neutron energy regime, for most elements and some isotopes of interest. It received mixed reviews but it served, at least, two purposes: first, it provided a target for criticism and second, demonstrated that although an enormous effort had been made to measure cross sections, relatively few excitation functions were defined by experiment.

By 1961, evaluated data sets for neutron induced reactions that included energy and angular distributions for secondary neutrons had been created at most installations that had need for such data. These data sets covered the incident neutron energy regime from sub-thermal energies (usually .01 or .001 eV) to 10, 15 or 20 MeV. A few included photon production data and energy deposits for residual nuclei. It occurred, essentially simultaneously, to many workers who created these estimated, guessed, or

semi-empirical data (later to be called evaluated data) that it was not efficient to have the same fields plowed by so many persons. Several informal consortia arose that planned to share the burden by interchanging sets of data and thereby lessening the effort expended at each installation. Because of varying interests at the different installations these efforts were only marginally successful and eventually gave way to participation in a more general and centrally sponsored effort.

During the first half of the decade of the sixties, considerable effort was expended in putting together an encoding system and computer-oriented formats such that a uniform representation of evaluated data could be used and thus facilitate the interchange of evaluations. During the fall and summer of 1963, the Reactor Computations and Mathematics Division of the ANS sponsored two meetings (one in New York City and one at Hanford, Washington) that culminated in the recommendation that an Evaluated Nuclear Data File (ENDF) encoding and formatting system should be created together with a "Center" whose responsibility would be the maintenance of the ENDF system and the collection and distribution of evaluated data. The basic idea was that existing evaluations would be translated into the ENDF system and then made available to users. The longer range plan was to replace existing evaluations with new and better data that would eventually become standard sets.

During the next two years, several meetings, sponsored by the USAEC, were held at Brookhaven National Laboratory. The objectives of these meetings were to consider a proposed encoding and formatting system (ENDF), and to make whatever modifications seemed to be necessary. They were well attended by representatives of interested laboratories, and after some modifications of the originally proposed system, an ENDF system was adopted. This system was so general in its ability to accept data in a variety of units and representations that it was difficult to use and this led to its becoming a

repository system, renamed ENDF/A. A new system ENDF/B that was considerably simpler was then created. With many modifications over the years, this is the system that is still used by most laboratories for receiving and transmitting data. Several years ago it superseded the ENDF/A system as a repository system so that the original ENDF system is now only of historical interest.

While the ANS interest in this field has continued through the years, the sponsorship of evaluation activities and the encoding system development was largely taken over by the AEC, later ERDA and still later DOE under the Golden Rule principle that "He who has the gold makes the rules." In June 1966, the first meeting of the Cross Section Evaluation Working Group was held at BNL under the sponsorship of the Division of Reactor Development and Technology of the USAEC. There were 26 participants representing 16 laboratories having reactor development interests, one representing the Advisory Committee on Reactor Physics and one from the USAEC. The minutes of that meeting with attachments were seven pages. By the May 1973 meeting the minutes and attachments were 176 pages. The first three meetings were limited to those laboratories that were active in reactor development. By the fourth meeting these restrictions were removed and the CSEWG became a truly national organization with participation of most laboratories that had an interest in or need for evaluated data. The CSEWG is almost "of age" now and the ENDF/B data files have gone through five versions and several "Mods" for each of the recent versions. Many, if not most, evaluations are done as collaborative efforts among two or more laboratories. Over the years the hospitality of the ENDF/B system has expanded progressively to accommodate extensions of the original neutron energy range, photon production data from neutron induced reactions, photon interaction data with un-ionized elements, formalized uncertainty files and, more recently, data for charged particle induced reactions.

To this point, what I have said could leave the impression that all has been orderly, logical and progressed smoothly. Such has not been the case, but it is not surprising that a cooperative effort among tens of laboratories and more tens of people would have developed with diversities of opinions as to how matters should progress. It is more germane that the emphasis on the importance of different neutron energy regimes has been a function of time and, in particular, a function of the funding agencies' interest at a specific time. For example, the first few versions of the ENDF/B files had particular emphasis on the very low neutron energy reactions because of the, then current, thermal reactor interest. By the time that the ENDF/B-IV files were issued, the Defense Atomic Support Agency (later Defense Nuclear Agency) with its interests and the fast breeder interests had caused a change in emphasis which amounted to raising the energy regime of interest and emphasizing photon production and interaction data. Since the expertise of any one evaluator does not span all materials and all energy regimes with equal facility, the degree of excellence of ENDF/B evaluations or of any one evaluation is not, in general, uniform. This problem has been alleviated, in part, by the mechanism of collaborative evaluations with two or more evaluators working on the same material; each dealing with his own area of greatest expertise. At some laboratories, including my own, local evaluated libraries are maintained that borrow freely from evaluations done by other ENDF/B evaluators but are generally quite different from the distributed ENDF/B libraries.

As an example, I shall describe the set of evaluated data libraries that are maintained at LLNL. We developed our own encoding system a few years prior to the establishment of the ENDF system. It was done in a "leap-frogging" mode with evaluators at AWRE, Aldermaston. To my knowledge, the first such encoding system was done at AWRE on an in-house basis. We took

what they had done and modified it with what we thought were improvements. We sent our data to them in our modified system and within a few months they had made further improvements in collaboration with evaluators from Winfrith. Their result was labeled the Aldermaston/Winfrith Nuclear Data File and was submitted to the international community in the form of a document ECSG/P11 ("A Possible International Punched Card/Magnetic Tape Format for Compiled Nuclear Cross Section Data"). At a meeting in Brussels of the EANDC Compilations Study Group in September 1963, just prior to the meeting at Hanford that I described at the beginning of this paper, there was unanimous approval that the A/WNDF system should be used and this approval included four U.S. representatives. Later that same month, there was a meeting at Aldermaston of representatives of AWRE, LLNL (then UCRL, Livermore) and LANL (then LASL). It was decided that the three laboratories would use the A/WNDF system for communicating with each other but would maintain their own systems within their respective laboratories. At the same time, a CSEWG-like arrangement was made in which responsibilities for evaluations of specific materials were parceled out among the three laboratories. One of the results of this collaborative effort was that several of the light isotope evaluations for the early ENDF/B versions were taken directly from these joint evaluations. Since both our energy regimes and materials of greatest interest did not coincide with those of the thermal reactor designers, we chose to continue to maintain and develop our own system and evaluations, with parts of the latter drawn from the work of other CSEWG evaluators. Our system has continued to be modified as new requirements have developed and we currently maintain four separate data files: ENDL (Evaluated Neutron Data Library), ACTL (Evaluated Neutron Activation Library), EGD (Evaluated Gamma-Ray Data Library), and ECPL (Evaluated Charged Particle Data Library). These files are

used at our installation, to some degree at LANL and by others. Our recent evaluations for neutron induced reactions have been done in large part in collaboration with Argonne National Laboratory and either have been or will be submitted to CSEWG as candidates for the ENDF/B-VI files.

To the extent that there will be a "wave of the future" in the nuclear evaluation field, it will likely be in the realm of charged particle induced reactions. There is an ongoing collaboration between LLNL and LANL to improve and extend the ECPL library which, although it has existed for about 15 years, needs upgrading and extension to complete it for five incident charged particles and for targets through oxygen. If their effort is funded, the Argonne group will carry out charged particle induced measurements and evaluations and join the LLNL/LANL collaboration. These evaluations will also be submitted for consideration for ENDF/B-VI. The extent to which new and revised evaluations will continue to be produced for neutron induced reactions will depend largely upon available funding. The current situation is precarious in terms of maintaining a "critical mass" of evaluators and other CSEWG participants. Most of the current effort is directed toward upgrading evaluations needed by the fast reactor program with a lesser effort being funded by Magnetic and Inertial Confinement Fusion for specific materials. Evaluation is an interface function. It lies intermediate between physical observation and theoretical interpretation on the one hand and a user community on the other. To have a future there must be both observers and users as well as evaluators. All three aspects are suffering from diminishing support and for the foreseeable future this trend is likely to continue.

In summary, evaluation activities in the U.S. have been continuous over the past quarter-century and for the past nineteen years have been largely centered in the CSEWG. From modest beginnings the intensity of these efforts rose to a maximum in the early to mid-seventies and have been declining since then. While my crystal ball is somewhat cloudy, I believe that evaluations will continue to be upgraded and expanded for the foreseeable future but with considerably diminished support. Hopefully, that support will not fall below that which is needed to maintain a viable activity.

I regret that time has not permitted acknowledgment of the contributions of the many individuals and laboratories whose work accomplished that which I have described. I am acutely aware that the only examples I used of non-CSWEG files are those of my own laboratory, but those are the ones with which I have greatest familiarity and I felt that, at least, one such example was required to avoid giving an unbalanced representation of the total evaluation activity in the U.S.

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